

Creep Deformation Lab Activity



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 **WARNING:**
This product can expose you to chemicals,
which are known to the State of California to
cause cancer. For more information, visit
www.P65Warnings.ca.gov.

 **WARNING:**
CHOKING HAZARD - Small parts
Not for children under 3 yrs.

Introduction

Rocks in the Earth can deform in many different ways, but the main distinction often made is if the deformation is brittle or ductile. Brittle deformation occurs in the cold upper crust where rocks are squeezed and store energy like springs. They keep storing more and more energy until they fail and break. This is the mode of deformation associated with things like earthquakes. Ductile deformation on the other hand is the slow movement of material, often associated with hot rocks under extreme pressures deep within the planet. Creep deformation is associated with tectonic scale deformation, flow of the Earth's mantle, and more.

There are even different styles of creep such as diffusion and dislocation creep. Diffusion creep is generally associated with higher temperature deformation and is the movement of vacancies in a crystal's structure through the material. Dislocation creep is the movement of a dislocation or imperfection in the crystal and generally is the dominant type of creep at lower temperatures. Dislocation creep doesn't depend on the grain size of the material, but diffusion creep does.

Since different materials melt at different temperatures, we talk about how "high" or "low" the temperature is relative to the melting point of the material. The ratio of the current temperature of the material to its melting point is called the homologous temperature.

$$T_H = \frac{T(\text{K})}{T_{mp}(\text{K})}$$

Similarly, we often do not want to worry about the absolute length of a sample, but we care much more about its change in length relative to its size. For example, shortening a football field by a meter would hardly be noticeable, but shortening your desk by a meter would be! To describe length change relative to the size of something, scientists use a quantity called strain. Strain is defined as the change in length divided by the initial length. The strain rate is the change in strain over time. For example a sample that was at a strain of 0.01 initially, then at 0.06 after 10 minutes would be experiencing a strain rate of 0.005 strain/minute.

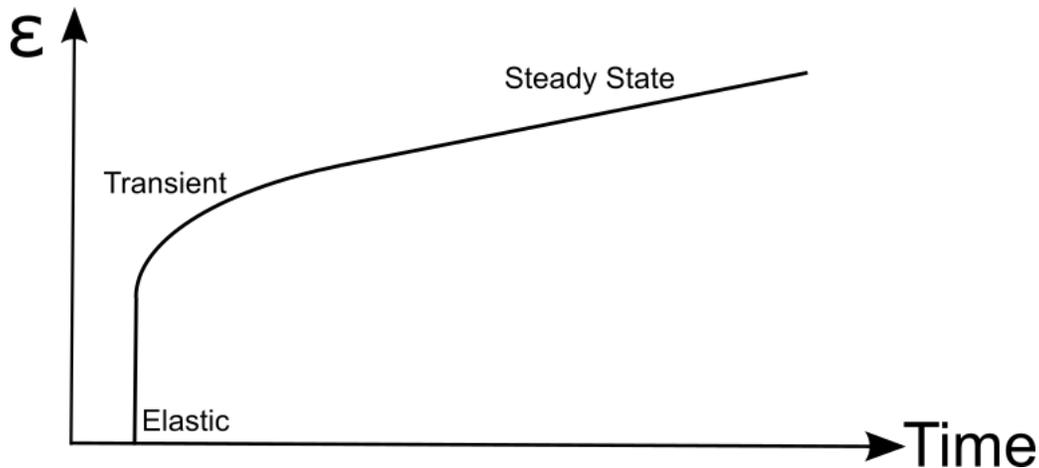
Dislocation creep is described as a "power law" relationship, meaning that it works in a non-linear way. It relates the strain rate of a material under a load to the stress and material/physical properties through the use of a "stress exponent".

$$\dot{\epsilon} = A\sigma^m \exp\left(\frac{-Q_c}{RT}\right)$$

There are several types of tests that we can run on a material - they involve different imposed sets of loading conditions called boundary conditions. We can either apply a constant load to a sample and see how it deforms and creeps under that load, or we can apply a constant crushing

motion to the sample (called a constant displacement or constant strain rate) and measure the force that results from that. Both tests should produce the same results, but due to the properties of materials certain types of tests are often easier to perform on certain materials. We will be using the constant load test, often referred to as a “dead weight” test since we apply a given load and leave it there for the duration of the test.

Assuming that the temperature, materials, and load remain constant we expect to see a sample strain in a predictable way over time. First, the sample loads elastically, or like a spring. This is recoverable deformation - if you remove the weight, the sample springs back. Next the curve becomes more shallow in the transient state. In this state deformation is becoming permanent as creep begins. Finally, the curve reaches a constant slope. The sample strain rate is constant and this represents the steady-state creep of the material.



With this information, scientists can better understand how the rocks in the Earth move and squeeze - letting us better understand our planet and what is happening to it over geologic time. Since rocks exist at many temperatures and pressures, these types of tests are repeated over and over again at many different conditions. Real world rocks are complex combinations of many minerals and it takes the effort of many dedicated scientists to catalog and understand them.

In your experiments, you'll be working with a material often used to simulate rocks at room conditions - paraffin wax. Wax has been used in “analog models” of the Earth for many years and lets us work out the basics of deformation on a simple material at normal temperatures and low stresses. (It also doesn't take years to deform!) We'll perform experiments at different loads and compute the stress exponent for the wax and compare it with results from other scientists or students in your class.

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Materials Needed

- Creep Deformation Apparatus
- Wax cylinders
- Weights (bricks, water bottles with shot, concrete, etc.)
- Computer and USB Cable

WARNING!!! This lab involves the use of heavy weights and presents a pinch hazard. Only perform this experiment with adult supervision.

1. Connect the USB cable from the circuit board on the machine to your computer.
2. If using the Leeman Geophysical software, start the program. Select the serial port of the device and click “connect”. If using a terminal program such as CoolTerm (free download), set the program to the appropriate serial port and a baud rate of 115200 baud. See the examples of each program below.
3. Measure a new wax cylinder using the provided calipers. Record the initial length and diameter of the sample.
4. Either obtain the weight of the loading platen and weights from your instructor or weigh them on a scale and record the weights.
5. Place the wax cylinder on the bottom platen and line it up with the loading rod. Once the rod is resting on the top of the cylinder, start recording data. This is done by clicking the “Clear” button on the Leeman Geophysical software or the recording function on your serial terminal. In CoolTerm this is the “Capture to Text/Binary File” function.
6. Place the first loading weight on the platens. We recommend 10, 20, and 30 pounds for the wax tests. Watch as the sample deforms and let the sample get to steady state deformation. The Leeman Geophysical software will draw a live graph of the data. When you are ready to stop collecting data, click the “Save” button (or stop the collection in your terminal program). If you don’t have a live plot of the data, we recommend letting the test run for 20-30 minutes.
7. After the test is complete, remove the load and then measure/record the final length and diameter of the sample.
8. Collect and save data for tests at three different loads. It is best to use a new wax cylinder for each test.
9. Work with Excel, MatLab, Python, or your tool of choice to follow the data processing exercises in the questions section that follows.

Name: _____

1. For our experiments we will be using paraffin wax which has a melting point of about 57°C. Calculate the homologous temperature assuming we do our experiments at room temperature 20°C. What type of creep would you expect? Why?

2. The data recorded from your experiment contains the time of each data point in milliseconds and the displacement from the displacement sensor in millimeters. Using your initial length measurements convert the displacement readings to real lengths of the sample. Check the final sample length with that you measured using the calipers. How close are your readings?

3. Convert the displacement readings into strain for each of the samples. What was the maximum strain reached for each sample? What are the units of strain?

Sample 1:

Sample 2:

Sample 3:

4. Make a plot of each experiment with time on the x axis in seconds and strain on the y axis.

5. Fit a line to the steady state portion of the curves. Record the slope of this line for each sample.

Sample 1:

Sample 2:

Sample 3:

6. Calculate the stress applied to the sample with each weight. The stress can be calculated by multiplying the applied weight (in kg) by gravity (9.81 m/s/s) and dividing by the area of the sample. The result is in Pascals.

Stress 1:

Stress 2:

Stress 3:

7. Make a log-log plot with stress on the x axis and strain rate (slope of the steady state deformation) on the y axis. These points should form a line. Fit a line to these points. The slope of this line is the stress exponent. Attach this plot.

Calculated stress exponent:

8. See the paper excerpt attached. How do your results compare with their results? What differences do you think there might be?

Rheological properties of paraffin as an analogue material for viscous crustal deformation

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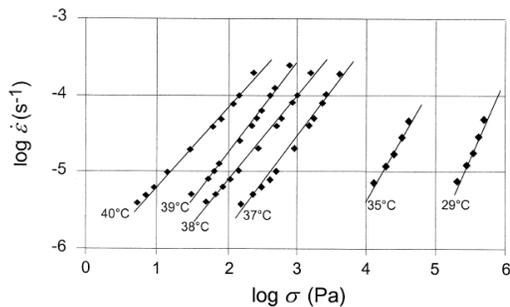


Fig. 2. Log-log plot of strain rate ($\dot{\epsilon}$) vs stress (σ) at different temperatures. Best-fit lines are also shown. See also Table 1.

Table 1
Stress exponent n at different temperatures and homologous temperatures

Experiment	T ($^{\circ}\text{C}$)	T/T_m	n
uniaxial test	29	0.55	2.11
uniaxial test	35	0.66	1.59
RSM800 test	37	0.70	1.32
RSM800 test	38	0.72	1.13
RSM800 test	39	0.73	1.21
RSM800 test	40	0.75	1.00